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9 A world of machines

Engineers use scientific knowledge to design and build machines that make life easier, bridges that carry heavy loads, and buildings that don't fall over. Machines transfer energy to or from an object by the action of a force. We all use machines every day to make life easier, sometimes without even noticing. The human body could not move without the many simple machines inside.

Think about machines

- How does a bathroom tap make life easier?
- Where can you find machines inside the human body?
- Who's the boss — you or your car?
- How could you lift many times your own weight by yourself?
- How did Archimedes try to prove that he could single-handedly move the whole Earth?
- Why do bicycles have gears?
- Why do roads wind around mountains instead of going straight up?

In this chapter:

9.1 A helping hand 278

9.2 Pushing uphill 283

9.3 Systems: Wheels and axles in a spin 285

9.4 Getting into gear 289

9.5 SCIENCE AS A HUMAN ENDEAVOUR Compound machines 291

9.6 Thinking tools: Single bubble maps and Venn diagrams eBook plus ONLINE ONLY

Study checklist/Digital resources 295

Looking back 296

ICT ACTIVITY projectsplus

Paper, Scissors, Robot 297

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YOUR QUEST

Exploring simple machines

A **machine** is a device that makes a physical task easier. That means that cars, bikes, cranes, lifts and escalators are machines. But machines like these are actually made up of many smaller machines called simple machines. Simple machines transfer energy from one object to another to make it move or change direction.

INVESTIGATION 9.1

As simple as a spoon

AIM To explore how a lever can make a task easier

Materials:
Milo can with lid (or similar)
teaspoon

METHOD AND RESULTS

- Place the lid firmly on the can.
- Try to remove the lid without using the teaspoon. If you succeed in removing the lid, replace it.
- Use the teaspoon to remove the lid. Replace the lid again.
- Use the teaspoon to remove the lid again, but hold the spoon much closer to the end near the lid.

DISCUSS AND EXPLAIN

1. How does the teaspoon make it easier to remove the lid?
2. Where should you hold the spoon to lift the lid most easily?

INVESTIGATION 9.2

Hard as nails

AIM To investigate the use of a lever to remove a nail from wood

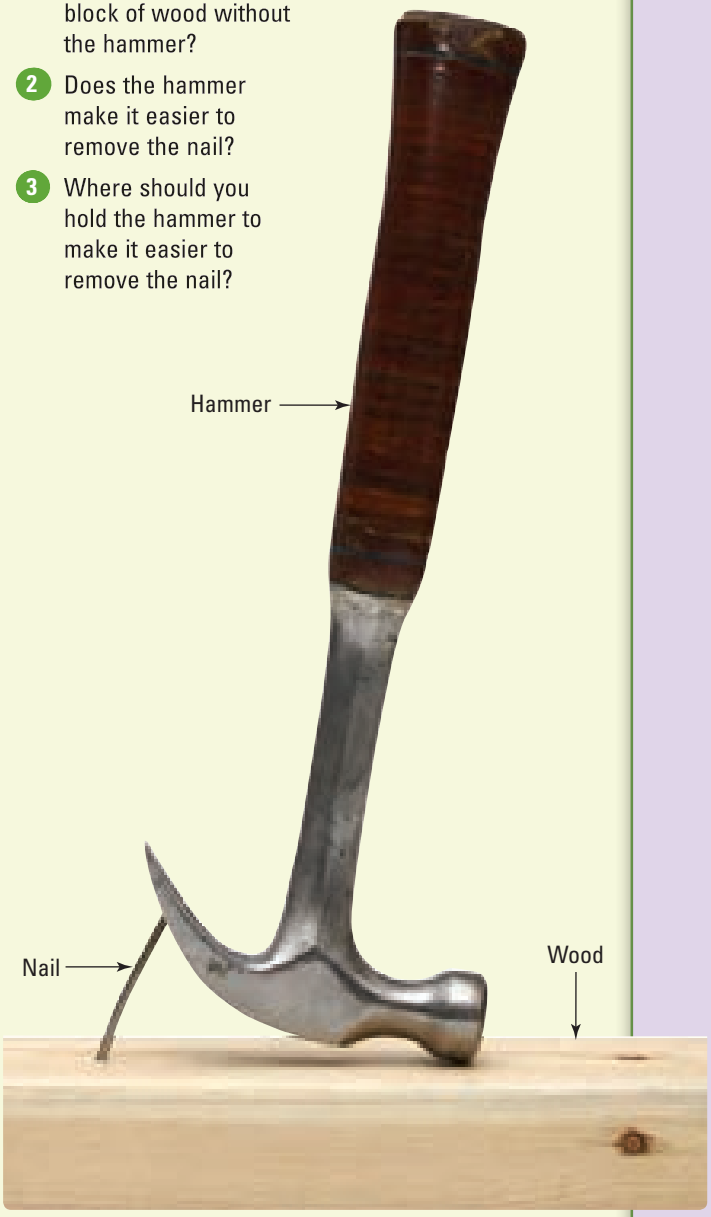
Materials:
claw hammer
nail in a block of wood

METHOD AND RESULTS

- Try to remove the nail from the block of wood without the hammer. Take care that you don't hurt your hand.
- Now use the hammer to remove the nail.

DISCUSS AND EXPLAIN

1. Would you have been able to get the nail into the block of wood without the hammer?
2. Does the hammer make it easier to remove the nail?
3. Where should you hold the hammer to make it easier to remove the nail?



A helping hand

Can-openers, scissors, tongs, spanners, hammers, brooms, tennis racquets and staplers are **levers**. A lever is a simple machine that uses the turning effect of a force.

The turning point of a lever is called its **fulcrum**. The resistance to motion that a lever works against is called the **load**. The force used to cause movement is called the **effort**.

WHAT DOES IT MEAN?

The word *lever* comes from the Latin word *levare*, meaning 'to make lighter'.

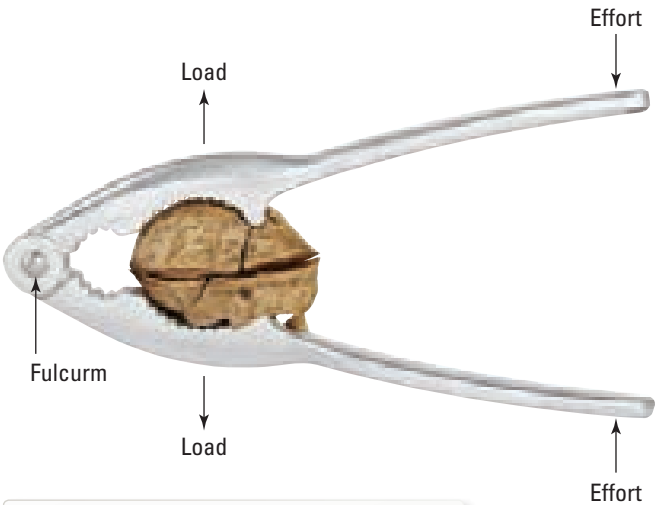
The lever shown in the illustration below is a **first-class lever**. The fulcrum lies between the effort and the load. A seesaw is another example of a first-class lever. First-class levers are **force multipliers** because they 'multiply' your effort.

Spoon being used as a first-class lever

The wheelbarrow and nutcracker shown below are also force-multiplying levers. However, the load is between the fulcrum and the effort. Such levers are called **second-class levers**. A door (not a sliding one!) is another example of a second-class lever.

What's the advantage?

The advantage of force-multiplying levers is that they allow you to move a heavy load with a small effort.



The wheelbarrow and nutcracker are examples of second-class levers. They allow you to move large loads that you would not be able to move without help.

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The **mechanical advantage** of a force-multiplying lever is defined as:

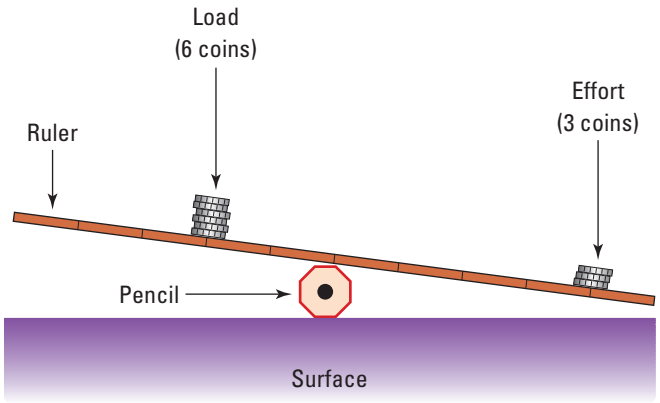
$$\text{mechanical advantage} = \text{load/effort}.$$

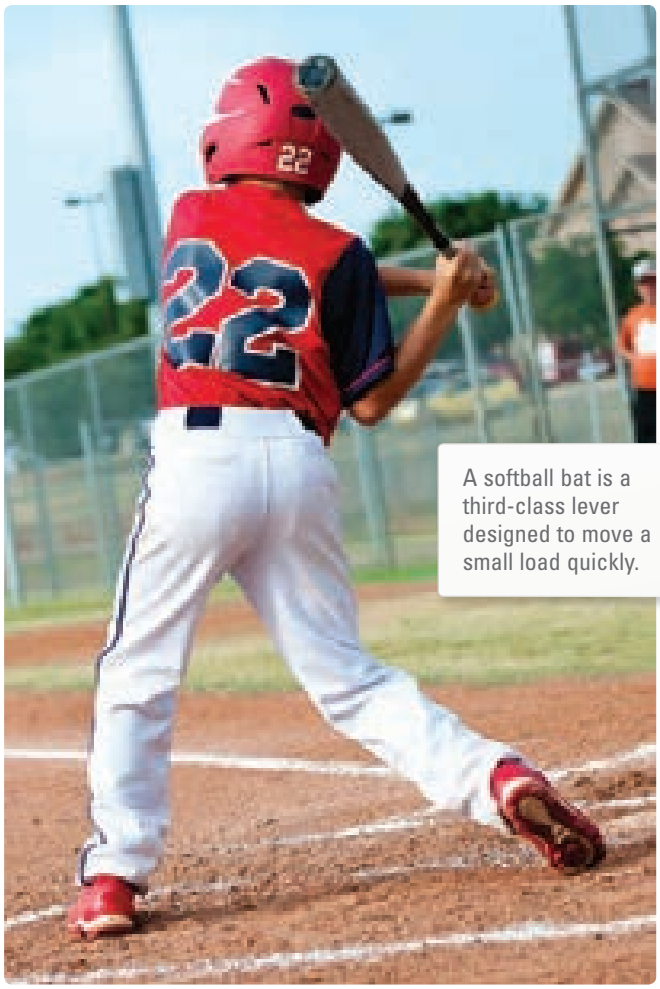
For example, when you use the lever below to raise a load of 6 coins with an effort of only 3 coins, the mechanical advantage is given by:

$$\text{mechanical advantage} = \text{load/effort} = 6 \div 3 = 2.$$

In other words, the lever lifts a load that is two times greater than the effort.

The mechanical advantage of this lever is 2.





A softball bat is a third-class lever designed to move a small load quickly.

Levers with the effort between the fulcrum and the load are called **third-class levers**. Third-class levers are not force multipliers. They move a load through a larger distance than the effort moves in the same time and are therefore **speed multipliers**. The softball bat shown above right is a third-class lever. Golf clubs, tennis racquets and brooms are also third-class levers designed to move a small load quickly with a large effort.

HOW ABOUT THAT!

Tooth decay was common on the goldfields of Australia in the nineteenth century because of poor diet and dental hygiene. Rotting teeth were usually pulled out by a local doctor. But if a doctor wasn't around, the blacksmith did the job with the same pliers used to pull the nails out of horseshoes. Ouch!

INVESTIGATION 9.3

Pushing your barrow

AIM To investigate how a wheelbarrow makes lifting a load easier

Materials:
wheelbarrow (or plank if a wheelbarrow is not available)
a few bricks

METHOD AND RESULTS

- Place a few bricks in the wheelbarrow and lift it by the ends of the handles.
- Without changing the load, lift the wheelbarrow with your hands as far down the handle as possible.
- While holding the wheelbarrow up, have your partner move the load so that it is closer to the handle.

1. How does the position of the effort affect its ability to raise the load?
2. How does the position of the load affect the amount of effort needed to raise it?

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INVESTIGATION 9.4

Get a load of this

AIM **To investigate the relationship between effort and its distance from the fulcrum**

Materials:
ruler at least 30 cm long
pencil
6 identical coins or 50-gram weights
plasticine (to hold pencil in place if it rolls)

METHOD AND RESULTS

1. Draw up a table like the one on the right.
- Use the pencil and ruler to set up a seesaw so that it balances without any weights on it.
- Place a load of three weights 4 cm to the left of the fulcrum. Place the other three weights (the effort) to the right of the fulcrum so that the effort balances the load.
2. Record the distance from the effort to the fulcrum in your table.
- Remove two of the weights from the effort and raise the load of three weights with an effort of only one weight.
3. Record the new distance from the effort to the fulcrum in your table.
- Experiment with your seesaw to see where various efforts need to be placed to raise loads of 5, 4 or 2 weights.
4. Record your observations in your table.
- Do some more testing, including raising small loads with a small effort.

DISCUSS AND EXPLAIN

5. Why is this type of lever called a force multiplier?
6. Examine the completed table to see whether any pattern is evident in your data. What is your conclusion?
7. Is there any advantage in using a seesaw-type lever to raise a light load with a large effort?

Raising a load with a first-class lever

Load		Effort	
Number of weights	Distance from fulcrum (cm)	Number of weights	Distance from fulcrum (cm)
3	4.0	3	
3	4.0	1	
5		1	
4		2	
4		1	
2		1	

A word about energy

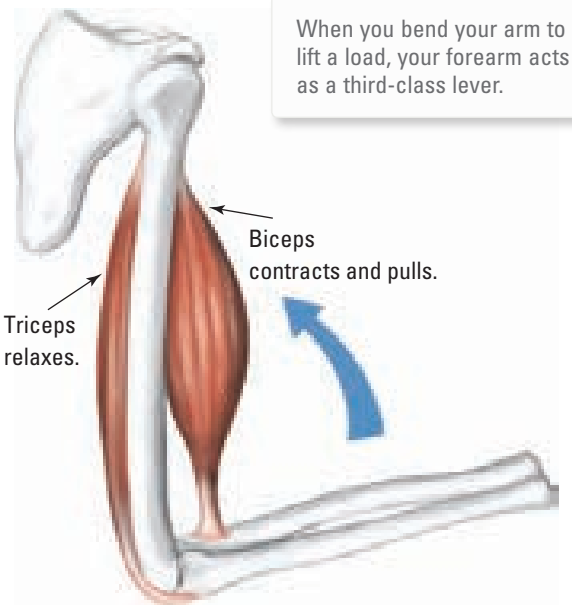
Although levers can 'multiply' a force or speed, the Law of Conservation of Energy is never broken. The Law of Conservation of Energy states that energy cannot be created or destroyed. It can only be transferred to another object or transformed into a different form. You can never get more energy out of a lever than you put in.

Body levers

Many of the bones in your own body are levers. The long bones in your arms and legs are the most obvious examples of levers. Joints such as your elbow and knee act as fulcrums. Your muscles pull on part of the bone to provide the effort. The load is the resistance to motion that your bone works against. The load could be the weight of a basketball, a soccer ball, a bucket of water or a heavy weight in the gym.

Levers in your arm

When you bend your arm to lift a weight, the effort is provided by your biceps muscle where it joins a bone called the radius in your forearm, just below the elbow. Your elbow is the fulcrum. It is the turning point of the lever. The load is the weight that you are trying to lift upwards. The effort is between the fulcrum and the load, so your forearm is acting as a third-class lever and a speed multiplier.



When you bend your arm to lift a load, your forearm acts as a third-class lever.

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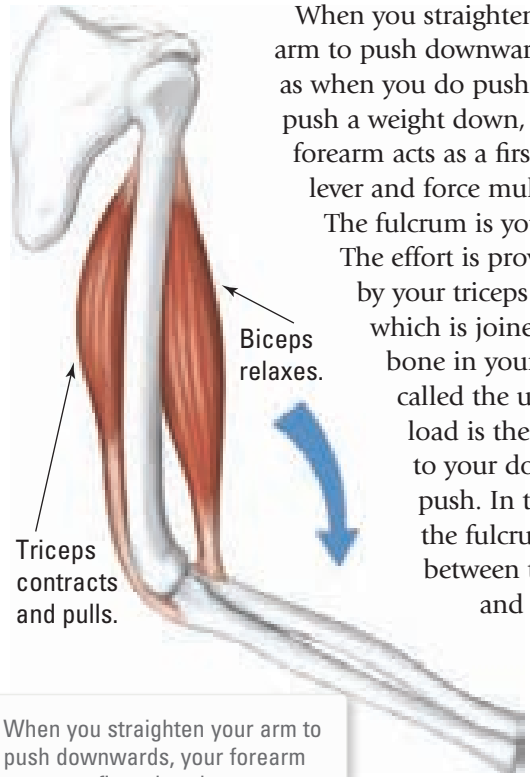


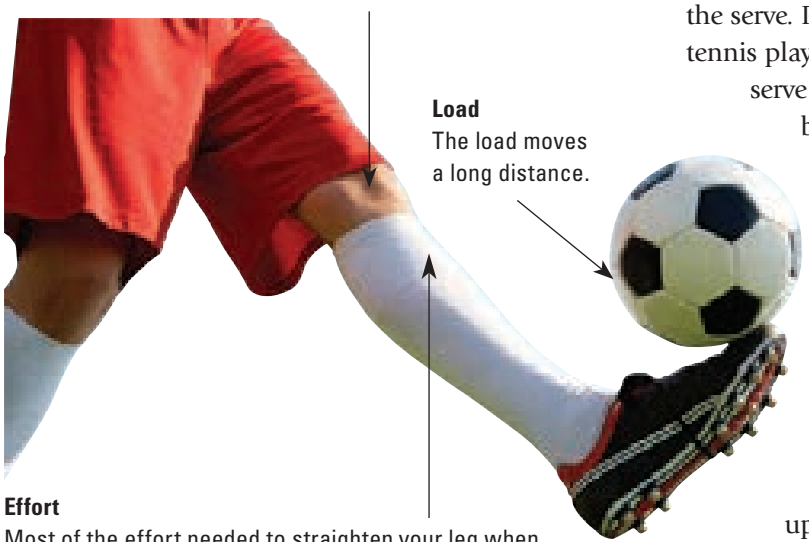
When you straighten your arm to push downwards, such as when you do push-ups or push a weight down, your forearm acts as a first-class lever and force multiplier. The fulcrum is your elbow. The effort is provided by your triceps muscle, which is joined to a bone in your forearm called the ulna. The load is the resistance to your downward push. In this case, the fulcrum is between the effort and the load.

When you straighten your arm to push downwards, your forearm acts as a first-class lever.

Kicking a ball

When a football is kicked, bones in the lower leg act as a third-class lever. The knee is the fulcrum. The effort needed to straighten the leg is provided by muscles attached to the top of the lower leg.

Fulcrum
The lower part of the footballer's leg pivots around the knee. The knee is the fulcrum in this lever.



Load
The load moves a long distance.

Effort
Most of the effort needed to straighten your leg when kicking a ball comes from the muscles in your legs. The effort to kick a ball is applied by muscles that attach to the top of your lower leg.

The load is the resistance to motion of the football. Although there is little movement where the effort is applied, the foot (where the load is) moves a large distance.

Anyone for tennis?

In ball games such as tennis, cricket, baseball, golf and hockey, racquets, bats, clubs and sticks are used as third-class levers. The end of the lever that strikes the load (the ball) moves much faster than the end of the lever where the effort is applied.

When a tennis ball is served, the lever consists of your whole arm and the tennis racquet. The fulcrum is your shoulder, the effort is applied by the muscles attached to the bones of your upper arm, and the load is at the centre of the racquet. The larger the distance between the load and the effort, the faster the serve. Professional tennis players can serve tennis balls at speeds of up to 240 km/h. This is many times the speed of the upper arm where the effort is applied.

When a tennis ball is served, the arm and tennis racquet work together as a third-class lever and speed multiplier.

Why warm up?

The muscles that pull on your bones to make them move are made up of tough and elastic fibres. When they are cold, the muscles are less elastic. If you overload muscles without warming up they can easily tear. Even with warming up, if muscles have not been prepared for sport by proper training, they can easily be torn when sudden movements are made.

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UNDERSTANDING AND INQUIRING

REMEMBER

1 Which body parts provide the effort when bones act as levers?

2 When you bend your forearm upwards to lift a bucket of water, it acts as a lever.
(a) Where is the fulcrum?
(b) Which muscle provides the effort?
(c) What is the load?
(d) Which type of lever is your forearm acting as?

3 When you straighten your arm to do push-ups, your forearm acts as a lever.
(a) Where is the fulcrum?
(b) Which muscle provides the effort?
(c) What is the load?
(d) Which type of lever is your forearm acting as?

4 Why is it important to warm up before playing sport?

5 What is a lever?

6 Explain why first-class and second-class levers are called force multipliers.

THINK

7 Why can't you get more energy out of a lever than you put in?

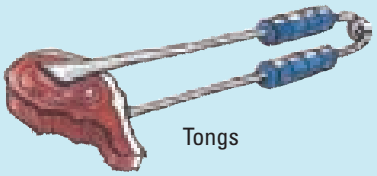
8 In cricket, the arm acts as a lever when the ball is bowled.
(a) Which class of lever is the arm acting as?
(b) Is the arm acting as a speed multiplier or a force multiplier? Explain your answer.
(c) Which part of the body acts as the fulcrum?

In cricket, the bowling arm is used as a lever.

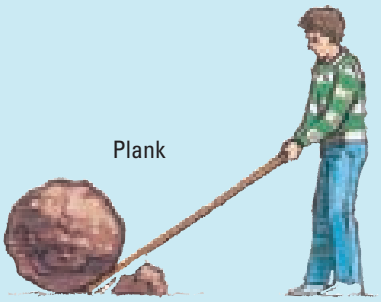
9 Is height an advantage to tennis players and cricket bowlers? Explain your answer.

10 Label the load, effort and fulcrum on a copy of each of the levers shown below.
(a) Which of the levers are speed multipliers?
(b) Which of the levers are second-class levers?

Shovel



Tongs



Plank

Door

11 Explain why third-class levers are called speed multipliers.

12 (a) What is the mechanical advantage of the lever in Investigation 9.4 when one coin is used to lift a load of three coins?
(b) To increase the mechanical advantage of the ruler and pencil in Investigation 9.4 to lift a slightly larger load, which way would you need to move the three coins?

13 Explain why door handles are placed as far away from the hinges as possible.

CREATE

14 Create a poster or short series of PowerPoint slides that could be used to encourage people to warm up before going for their daily run around the block.

INVESTIGATE

15 Find out what the scientists in the Movement Science Department of the Australian Institute of Sport are researching to improve the performance of Australian athletes.

16 Serious athletes don't just warm up. They also go through 'cooling down' exercises after strenuous activity. Find out why they do this.

17 Learn how a spanner multiplies force by completing the **Spanner** interactivity in your eBookPLUS. **int-0023**

eBookplus work sheet 9.1 Loaded levers

Pushing uphill

Imagine how difficult it must have been for the ancient Egyptians to build the pyramids at Giza.

The Great Pyramid was built from over 200 million blocks of limestone, most with masses over 2 tonnes. It is believed that the blocks were dragged from nearby quarries by gangs of men. The task of lifting the blocks to heights of over 140 metres was made possible by building long ramps of brick and sand. As each layer of limestone blocks was completed, the ramps were extended so that the next layer could be commenced.

WHAT DOES IT MEAN?

The word *ramp* comes from the Old French word *ramper*, meaning 'to climb'.

Inclined planes

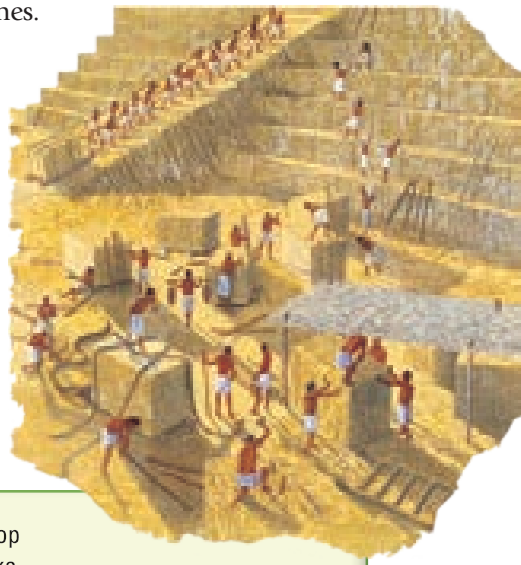
A **ramp** is a machine because it makes the physical task of raising an object easier. A ramp is simply an **inclined plane** — a surface that is set at an angle to the horizontal. It allows objects to be raised with less effort than would be needed to lift them straight up. Ramps are used in shopping centres and other buildings to allow wheelchairs, prams and strollers to be raised with less effort. Although a smaller effort is needed when using a ramp, the load must be moved through a larger distance. Escalators are moving ramps. The winding mountain road in the photograph on the next page is also a ramp.

Imagine how much shorter the trip would be if the road went straight up the mountain — but no vehicle would be powerful enough to use the road.

When an object is pushed up an inclined plane, energy is transformed from the energy of movement (kinetic energy) into stored energy (potential energy). If an object at the top of an inclined plane is allowed to slide or roll down, some of its potential energy is transformed back into kinetic energy.

Inclined planes at work

Wedges are inclined planes. They can be used to penetrate or split objects, or to stop them from moving. Axes, knives and your front teeth are examples of wedges. They reduce the force needed to cut through objects. If you have ever tried to cut through a hard



INVESTIGATION 9.5

Inclined to make it easier

AIM **To investigate how an inclined plane makes a task easier**

Materials:

3 textbooks
500-gram mass with hook
ramp (thin piece of wood)
spring balance

METHOD AND RESULTS

- Place three textbooks on top of each other. Measure and record the height of the textbooks.
- Place the 500-gram mass next to the pile of books and use the spring balance to slowly lift the mass so that its base is level with the top of the pile.

1. Record the force measured by the spring balance.
2. Lean a ramp against the pile of books. Measure and record the distance from the bottom of the ramp to where it meets the top edge of the pile of books.

- Place the 500-gram mass at the bottom of the ramp and use the spring balance to slowly pull it until its far end reaches the top of the pile.

3. Record the force measured by the spring balance.

DISCUSS AND EXPLAIN

4. Does it take more force to lift the mass straight up or along the ramp?
5. In which case does the mass have to move further — straight up or along the ramp?
6. Which method of raising the mass is better? Why?
7. The mechanical advantage of a simple machine is a measure of the number of times greater a load is than the effort (see section 9.1). What is the mechanical advantage of your ramp?

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piece of food like an apple with a blunt knife, you will know the value of a wedge.

Screws are inclined planes. A screw is a curved ramp. However, instead of an object being pushed up the ramp, the ramp is pushed down into the object. The ramp cut into a screw is called the **thread**; the distance between two turns of the thread is called the **pitch**. Because the total length of the thread is so great, its force-multiplying effect is very large. Most car jacks use a large screw to lift a huge load with little effort. Similarly, a corkscrew is used to penetrate the tightly fitted cork of a wine bottle with little effort. The cork is then removed by pulling the corkscrew out directly.

This winding mountain road is a ramp.

INVESTIGATION 9.6

Inclined planes on the move

AIM To investigate how a wedge makes a task easier

Materials:

wooden door wedge
2 rubber bands
2 blocks of wood (soft pine)
self-tapping screw
screwdriver

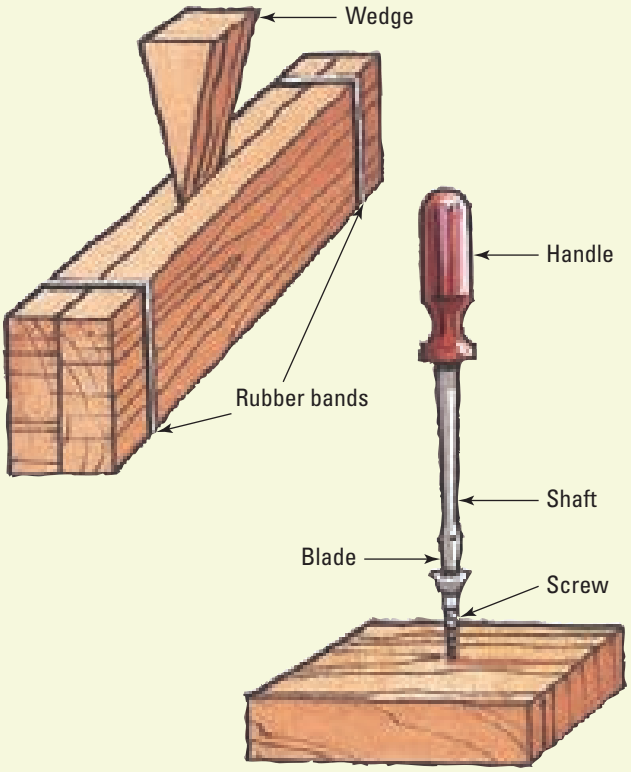
METHOD AND RESULTS

- Use two rubber bands to hold the two blocks of wood together. Try to pull the two blocks of wood apart with your fingers. Take care not to break the rubber bands.
- Place the sharp edge of the door wedge between the two blocks and push it down.
- Use the screwdriver to insert the screw halfway into one of the blocks of wood. Look closely at the thread of the screw as it moves into the wood.

1 Does the wedge make it easier to separate the two blocks?

DISCUSS AND EXPLAIN

2 Would you have been able to get the screw halfway into the wood by pushing straight down on it?



UNDERSTANDING AND INQUIRING

REMEMBER

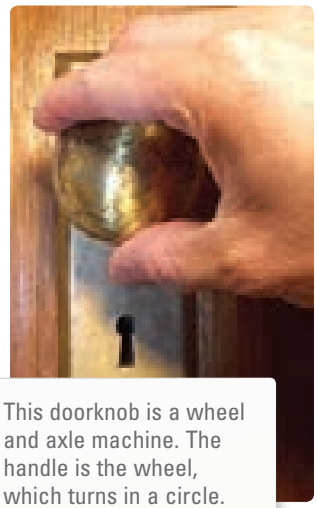
1 What is a ramp?
2 Ramps are inclined planes. List two other types of inclined planes.
3 What energy transformation takes place when an object is pushed up an inclined plane?
4 What is the difference between the thread of a screw and the pitch of a screw?

THINK

5 A ramp makes it easier to push or pull objects upwards. What is the 'penalty' for making the task easier?
6 Explain why inclined planes are classified as force multipliers.
7 Construct a table with three columns headed 'Ramps', 'Wedges' and 'Screws'. Brainstorm with a partner or small group to list as many examples of each type of inclined plane as you can.
8 Explain how a ramp is able to produce a mechanical advantage.

Systems: Wheels and axles in a spin

A circular doorknob is a simple machine called a **wheel and axle**. It is actually a lever that can rotate. The inner, smaller wheel of the doorknob is the axle. When you open a door you apply an effort to the wheel and the axle pulls on the load to open the door. The fulcrum, or turning point, is at the very centre of the doorknob.



This doorknob is a wheel and axle machine. The handle is the wheel, which turns in a circle. The spindle inside is the axle, and it turns in a smaller circle.

The doorknob in the photo is a force multiplier. You apply a small effort to the wheel to move a large load with the axle. There is, however, a penalty; you pay for the extra force with extra distance. The wheel (handle) moves further than the axle. Imagine, however, how difficult it would be to turn the axle without a handle.

Bathroom taps and car steering wheels are also force-multiplying wheels and axles. Can you think of any others?

Speed it up

Wheel and axle machines can be used to make things move faster. The ceiling fan in the photograph below is a wheel and axle machine. A large force is applied to the axle. Each time the axle turns, the fan blades move a much greater distance in the same amount of time. It is a speed multiplier. The ceiling fan transfers kinetic energy, from the motor that makes the axle turn, to the fan blades.

A car wheel is another example of a speed multiplier. The axle turns when a large force is applied to it. The outside of the wheel moves faster, covering a much greater distance in the same time.

Pairs of wheels and axles are sometimes joined together with a chain or belt. This either reduces the effort needed to make one of the wheels turn or makes one of the wheels turn faster.

The fanbelt in a car is one example. Wheels and axles joined by belts are also used to operate heavy machinery in factories.

This ceiling fan is a speed-multiplying wheel and axle machine. The fan blades trace out a complete circle. Electricity is used to make the axle turn, and the fan blades move faster than the axle.

INVESTIGATION 9.7

Getting a handle on wheels and axles

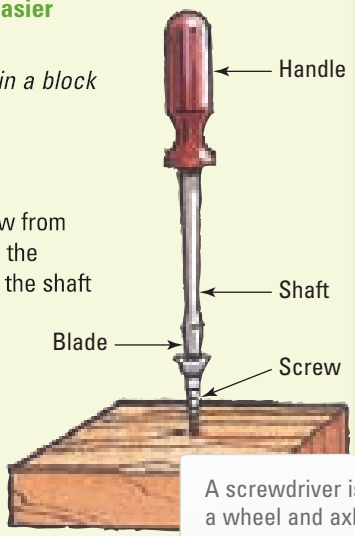
AIM To investigate how wheels and axles make a task easier

Materials:

screw firmly embedded in a block of wood
screwdriver

METHOD AND RESULTS

- Try to remove the screw from the block of wood with the screwdriver by turning the shaft instead of the handle.
- Remove the screw by using the screwdriver as it is meant to be used — by turning the handle.
- Use the screwdriver to replace the screw firmly into the wood.



A screwdriver is a wheel and axle.

1. Can the screw be removed by turning the shaft?

DISCUSS AND EXPLAIN

2. What difference does using the handle make to the effort needed to remove the screw?
3. During one full turn of the screwdriver, which moves further — the outside edge of the handle or the outside edge of the shaft?

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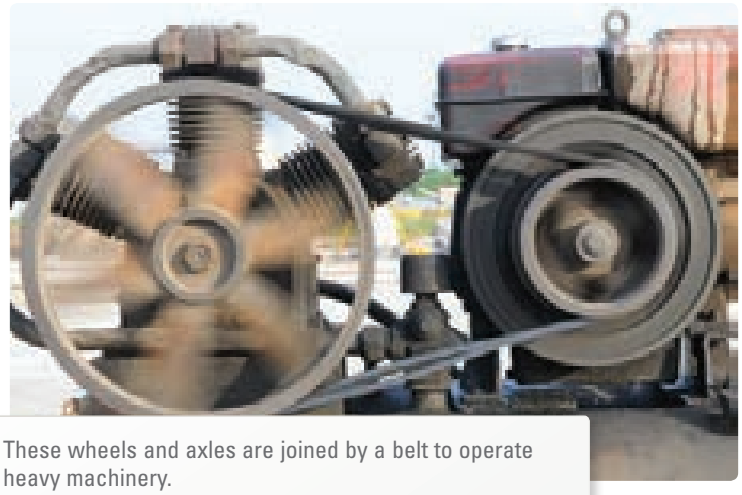


These wheels and axles are joined by a belt to operate heavy machinery.

A single pulley simply changes the direction of the effort needed to lift a load.

INVESTIGATION 9.8

Wheels and axles at work

AIM **To investigate how wheels and axles can become force or speed multipliers**

Materials:

selection of wheels and devices (for example, doorknob, hand drill, toy cars, spinning toys, wind-up toys, taps, screwdrivers, wing nut, small wheels)

METHOD AND RESULTS

- Examine the wheel and axle machines provided.
- Draw a diagram, labelling the wheel and axle.

For each machine examined:

1. Write down whether it is a force multiplier or a speed multiplier.
2. Explain, in your own words, how it works.

Getting a lift

A pulley is a special type of wheel and axle that makes it easier for you to lift a load. The wheel has a groove around it so that a rope or cable can be passed over or under it. A pulley does not decrease the size of the force, or effort, needed to lift the load. It changes the direction of the effort.

It is easier to pull down on a rope to lift a load than it is to push the load. Your own weight can be used to advantage.

When more than one pulley is used, a large load can be lifted with a small effort. A system of two or more pulleys therefore acts as a force multiplier. It magnifies the size of the effort. As with other force multipliers, there is a cost. The rope needs to be pulled through a large distance to move the load through a small distance.

A block and tackle is used to lift or pull heavy loads.

A multiple-pulley system is usually called a **block and tackle**. The block is the frame around the pulleys. The tackle is the string or cable joining the load to the effort. With a block and tackle it is possible to lift many times your own weight. Of course, you have to pay for it by pulling over a long distance.

The woman in the photo above is using the pulley to **transfer** energy from herself to the weight to make it move. In order to move the load, her muscles need to **transform** the chemical energy that she has stored by eating food into movement energy of her arms.

A block and tackle system is used in garages to lift engines out of cars. It is also used on cranes, wharves and ships.

HOW ABOUT THAT!

Archimedes (287–212 BC), a Greek mathematician, invented the multiple pulley system. It is believed that he boasted to King Hiero II of Syracuse: 'Give me a place to stand on, and I shall move the whole Earth'. The king challenged Archimedes to prove it. Archimedes responded by using a system of pulleys to single-handedly drag a ship, fully loaded with cargo and passengers, out of the water and onto land.

ONLINE PAGE PROOFS

INVESTIGATION 9.9

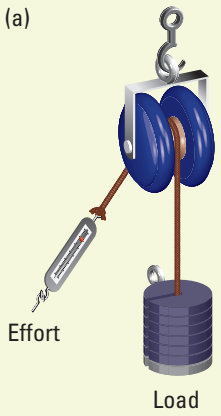
Lifting that load

AIM **To compare the mechanical advantage of three pulley arrangements**

Materials:
2 single pulleys
2 double pulleys
1-metre length of string
set of slotted 50-gram masses
5.0-newton spring balance
metre ruler
hook from which to suspend pulleys

METHOD AND RESULTS

1. Draw up a table for your results like the one below.
- Load the slotted masses to a mass of 400 grams and attach them to one end of the string.
- Use the spring balance to measure the weight, in newtons (N), of the slotted masses. This weight is the load that must be lifted.



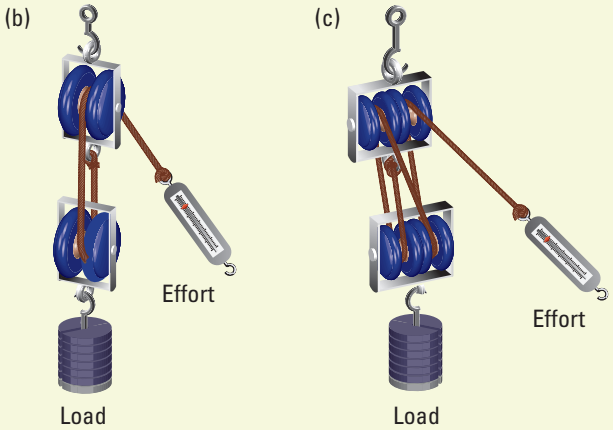
2. Record the load in your table.
- Thread the other end of the length of string over the wheel of a single pulley and attach it to the spring balance as shown in diagram (a) above.
- Pull slowly on the spring balance so that the load is lifted slowly and steadily upwards through a distance of 5 cm.

3. Record the force in newtons (N) measured by the spring balance. This force is the effort. Also record the distance through which you had to pull the spring balance to lift the load 5 cm.
- The distance moved by the effort (your pull on the spring balance) is called the effort distance.
- Arrange the system with two single pulleys as shown in diagram (b). The pulleys should be about 10 cm apart.
- Pull slowly on the spring balance to lift the load steadily.

4. In your table, record the force and effort distance needed to lift the load through a distance of 5 cm.
- Repeat the previous two steps using the system with the two double pulleys shown in diagram (c).

DISCUSS AND EXPLAIN

5. How does the effort needed to lift the load using two single pulleys compare with that needed to lift it with one single pulley?



The pulley systems to be tested in the experiment: (a) single pulley (b) two single pulleys (c) two double pulleys

6. How does the effort needed to lift the load with two double pulleys compare with that needed to lift it with one single pulley?
7. Would it be true to say that the system with two double pulleys has the same advantage as one with four single pulleys? Why?
8. Looking at your tabulated results, how would you say the effort needed changes as the number of pulleys increases?
9. How does the effort distance change as the effort itself decreases?
10. Predict how much effort would be needed to lift the same load by 5 cm if you used two triple pulleys instead of two double pulleys. How far would you need to pull on a string to lift the load 5 cm?

Lifting a load with pulleys

Pulley arrangement	Load (N)	Load distance (cm)	Effort (N)	Effort distance (cm)	Mechanical advantage (load/effort)
Single pulley		5.0			
Two single pulleys		5.0			
Two double pulleys		5.0			

ONLINE PAGE PROOFS

UNDERSTANDING AND INQUIRING

REMEMBER

1 Which part of a circular doorknob is the wheel? Which part is the axle?

2 Explain why a circular doorknob is called a force multiplier.

3 Explain why a ceiling fan is called a speed multiplier.

4 How is a single fixed pulley useful even though it does not decrease the size of the force needed to lift a load?

5 Why is a system of two single pulleys better than one single pulley for lifting very heavy loads?

6 What is a block and tackle? What is it used for?

THINK

7 Draw a diagram of the car steering wheel shown below.
- (a) Draw an arrow to show where the effort is applied when turning right.
- (b) Label the wheel and the location of the axle.
- (c) What is the load being moved by the steering wheel?
- (d) Is the steering wheel a force multiplier or a speed multiplier?
- (e) If you wanted to change your steering wheel to one that was easier to turn, should you get a larger one or a smaller one?

A car steering wheel is a wheel and axle machine.

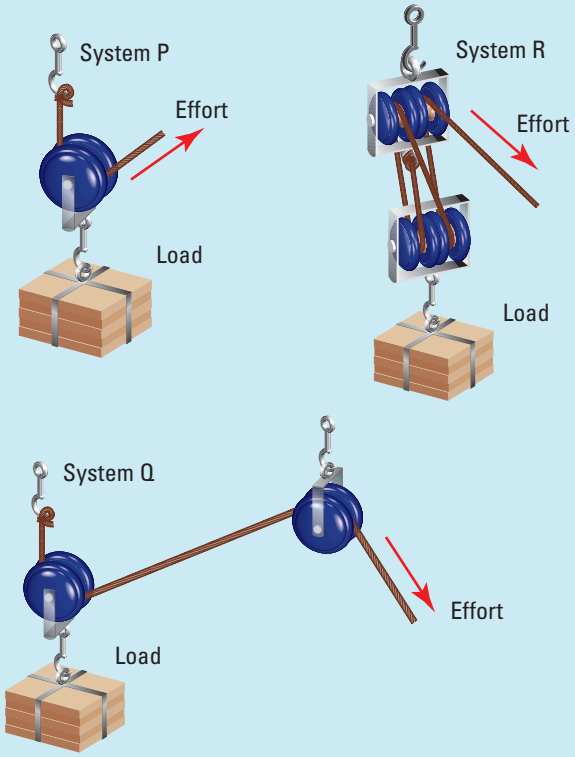
8 Draw up a two-column table with the headings 'Force multipliers' and 'Speed multipliers'. List as many wheel and axle machines as you can think of in the appropriate column.

9 It has been said by many people: 'You don't get anything for nothing'. How does this statement apply to multiple-pulley systems that make it easier to lift a load?

10 Complete the equation:

load × load distance = effort × _____.

11 In the diagram below, which of the systems P, Q and R would you need to:
- (a) apply the least effort
- (b) apply the most effort
- (c) pull the string through the greatest distance
- (d) apply an effort equal to the load
- (e) apply an effort equal to half of the load?



CREATE

12 Make a model wheel and axle. Use cotton thread and two sets of slotted weights to show how your model can be used as a force multiplier.
- (a) Calculate the mechanical advantage of your wheel and axle.
- (b) Does your model change energy from one form to another? If so, describe the change in detail.

INVESTIGATE

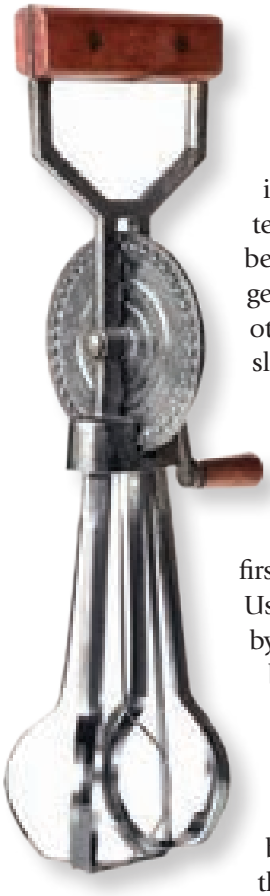
13 Investigate the wheels and axles on a bicycle.
- (a) How many are there?
- (b) What is the purpose of each wheel and axle?
- (c) What is the purpose of the chain?

14 Find out more about Archimedes and the machines he invented. He is probably more famous for Archimedes' Principle than for any of his inventions. What is Archimedes' Principle?

eBookplus work sheet 9.2 Measuring forces

Getting into gear

Most people associate gears with cars or bikes, but you can also find gears in the kitchen.



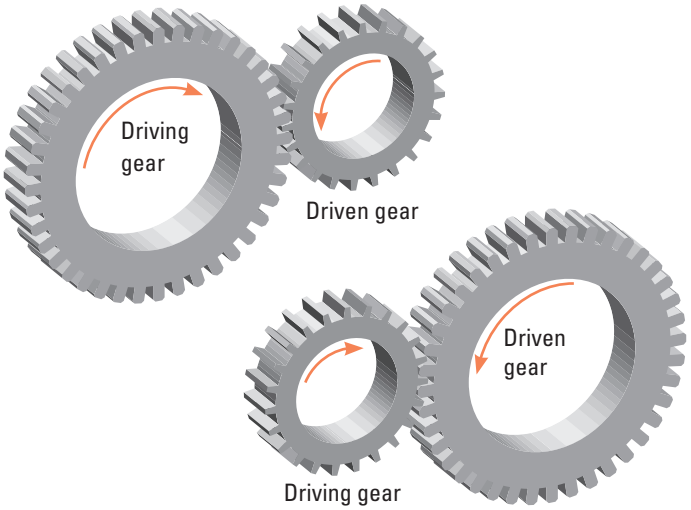
A hand-operated eggbeater has gears that are used to change both the direction and speed of motion.

Each of the **gears** in a clock is simply a wheel and axle with teeth. The teeth of one gear fit between the teeth of another gear. When one gear turns, the other can be made to turn faster, slower or in a different direction. The gears in the clock allow the three hands to move around the face of the clock at different speeds.

The wheel that is moved first is called the **driving gear**. Usually the driving gear is moved by a person or a motor. On a bicycle, it is moved by pedalling, while in the eggbeater shown at left the driving wheel is moved by the handle.

The wheel that is moved by the driving gear is called the **driven gear**. In a hand-operated eggbeater there are two driven gears.

The gears in this clock allow its three hands to move around its face at different speeds.



INVESTIGATION 9.10

Looking at gears

AIM To investigate how a machine with gears makes a task easier

Materials:
hand-operated eggbeater or hand drill

METHOD AND RESULTS

- Identify the driving gear and the driven gear or gears.
- Rotate the driving gear and observe the motion of each driven gear.

1. Count and record the number of teeth on the driving gear and the number of teeth on each driven gear.
2. Use the handle to rotate the driving gear slowly through one complete turn, while your partner counts and records the number of turns completed by each driven gear.

DISCUSS AND EXPLAIN

3. Which is larger, the driving gear or each driven gear?
4. Which moves faster, the driving gear or the driven gears?
5. Is this system of gears working as a force multiplier or as a speed multiplier?
6. How many times does each driven gear turn for each rotation of the driving gear?
7. Does the number of teeth on each gear seem to affect the way the gear system works? In what way?

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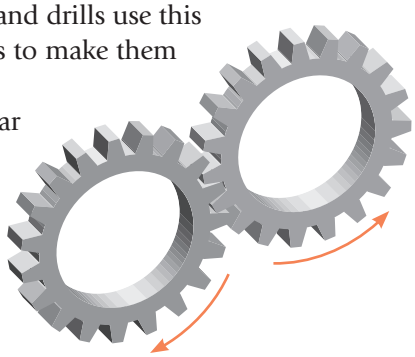
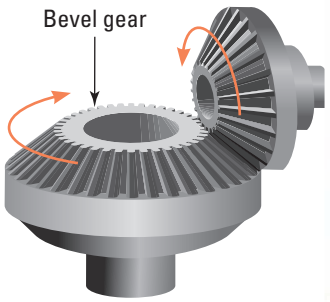
Big wheels, small wheels

Different sizes and arrangements of gears are used to make wheels turn faster, slower or in different directions.

A large driving gear makes a small driven gear move faster, but in the opposite direction. Hand-operated eggbeaters and drills use this combination of gears to make them spin quickly.



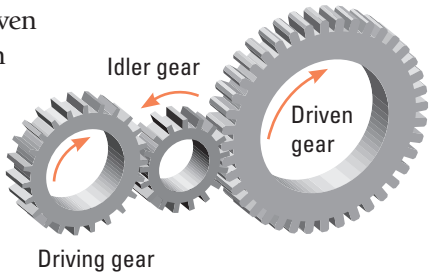
A small driving gear makes a large driven gear move slower but in the opposite direction. This arrangement acts as a force multiplier. It is used to move large loads with a small effort. This arrangement is used in cars to allow them to climb hills or gather speed quickly. It is also used in rotating shopwindow displays to make them turn slowly.



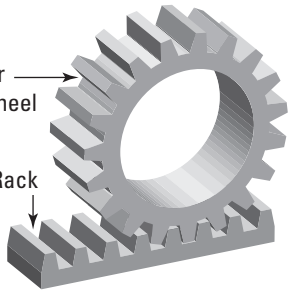
Pairs of gears the same size change the direction of turning without changing the speed.

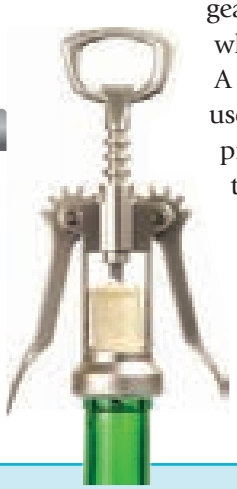
Gear wheels at right angles to each other can change vertical motion into horizontal motion. Hand-operated eggbeaters and drills use this arrangement.

An idler gear can be used between the driving and driven gears to make them turn in the same direction. Why do you think that it is called an idler gear?



Rack and pinion gears consist of a flat row of teeth, called a rack, and a circular gear wheel. A corkscrew uses rack and pinion gears to change the circular movement of the driving gears into the upward, straight-line movement that pulls the cork out.





This corkscrew uses rack and pinion gears.

UNDERSTANDING AND INQUIRING

REMEMBER

1 What are gears?

2 What is the difference between a driving gear and a driven gear?

3 Which gear turns faster if:
(a) the driving gear is larger than the driven gear
(b) the driving gear is smaller than the driven gear
(c) the driving gear is the same size as the driven gear?

4 What can gears do, other than make another wheel turn faster?

THINK

5 List as many devices that use gears as you can.

6 The driving gear on a hand-operated eggbeater has 40 teeth while each driven gear has 10 teeth.
(a) How many times will the blades of the eggbeater turn for each turn of the handle?
(b) How could you change the design of the eggbeater so that you could move the blades faster without moving the handle faster?
(c) How could you change the design of the eggbeater so that it is easier to turn the handle? What would be the disadvantage of doing this?

7 Learn how gears are used to make a wheel turn faster by completing the **Gears** interactivity in your eBookPLUS. **int-0025**

8 Investigate the effect of different sized gears by completing the **Gear ratios** interactivity in your eBookPLUS. **int-0746**

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CREATE

9 Use Legotechnic® or a similar kit to build a machine with at least two gears that can be used with a handle to:
(a) lift a heavy load
(b) make a wheel turn in the same direction as the handle
(c) make a wheel turn in the opposite direction from the handle.

eBookplus work sheet 9.3 Which way?

Compound machines

A bicycle is a compound machine made up of many simple machines. The obvious ones are the front and rear wheels, handbrake and pedals. But if you look carefully you can find many others.

All compound machines are made up of two or more simple machines, including levers, wheels and axles, pulleys and gears.

On your bike

Front and rear wheels

Each of the front and rear wheels is an example of a wheel and axle. The rear wheel is made to turn by another wheel and axle — the pedals. The axle of the pedals is joined to the axle of the rear wheel by a chain. The rear wheel and axle is a speed multiplier. The rear wheel axle is much smaller than the back wheel. When it turns, the back wheel turns very quickly. The front wheel is pushed along the road by the rest of the bicycle.

Gears

The gears on a bicycle usually act as speed multipliers. Bicycle gear wheels are called sprockets. Although the front and rear **sprockets** are connected by a chain, they work just like gears with teeth that fit together. The front sprockets are larger and have more teeth than the rear sprockets.

The highest wheel speed can be reached with the least effort when the larger front sprocket is used with the smallest rear sprocket. This combination is most suitable when riding quickly on a level road. When riding up a steep slope, speed is less important. If the smaller front sprocket is used with the largest rear sprocket, you can climb the slope with less effort. You do, however, need to make more turns of the pedals.

Handbrake

The handbrake is an example of a first-class lever. The fulcrum is between the effort and the load. When the rider squeezes the handle of the handbrake, the effort is transferred along a cable to the brake pads that push against the wheel.

On four wheels

The car is also a compound machine. But it is made up of many more simple machines than the bicycle. Most of the simple machines in a car are under the bonnet, but the most obvious ones are the wheels and axles that roll along the road, and the steering wheel.

HOW ABOUT THAT!

One of the first bicycles invented was called the 'swiftwalker'. It didn't have pedals. The rider had to push off the ground with one foot to make the bike go forwards. The rider could then sit while the bike coasted forwards. Going downhill was a breeze, but imagine trying to go uphill! To make matters worse, the wheels were made of wood with iron rims covered with leather. It was a very bumpy ride!

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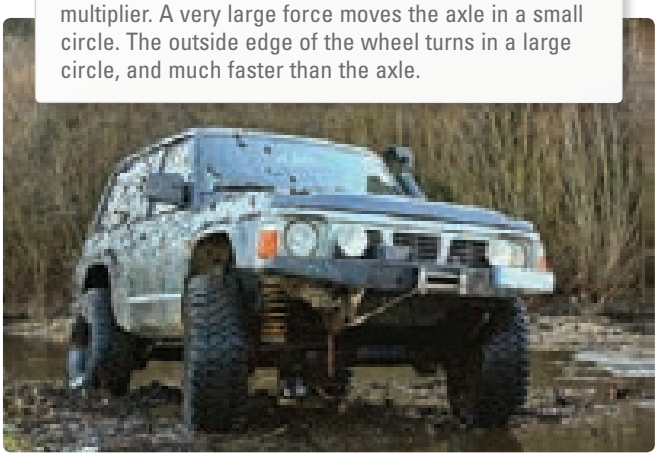


The front wheel and axle of this vehicle act as a speed multiplier. A very large force moves the axle in a small circle. The outside edge of the wheel turns in a large circle, and much faster than the axle.

Fuelling compound machines

Machines don't create energy. They reduce the effort you need to apply, or they reduce the distance over which you need to apply a force. The Law of Conservation of Energy applies to all machines. The total energy you can get out of a machine is equal to the amount of energy that you (or a fuel) puts in. However, the total amount of *useful* energy you get out of a machine is always less than the amount that goes into it. That's because some energy is always lost to the machine or the surroundings as heat.

Many simple machines and some compound machines, including bicycles, scooters and skateboards, are fuelled by the energy a person provides. Most motor vehicles are fuelled by petrol, gas, diesel or ethanol. Before 1920, many cars were fuelled by steam, transferring the energy of the gas particles to drive a motor, which turned the wheels. The steam was obtained by burning coal or wood to boil water.

Steam engines were much more suitable for fuelling trains than cars because they could carry large amounts of coal or wood on board. Even though steam-fuelled trains have been largely replaced by diesel or electric trains, there are still many in service throughout the world.

Steam-fuelled trains are still in use throughout the world, often as popular tourist attractions.

Well-oiled machines

Friction is an enemy of compound machines and some simple machines, such as wheels and axles, gears and pulleys. When moving parts rub against each other, they heat up and cannot move quickly. To avoid problems caused by friction, the moving parts of machines need to be:

- kept free from dirt and dust
- lubricated with grease or oil.

As mechanical systems, machines are designed to transfer energy by the action of a force. Energy transferred within a machine as heat is energy wasted.

Compound machines are designed by **mechanical engineers** and kept safe and in working order by **mechanics**. The challenge for engineers is to design machines that are safe, energy efficient and suitable for the conditions in which they are used. Mechanics are to compound machines what medical practitioners are to people. They are problem solvers — keeping the machines they work on in good working order and finding ways to fix problems and, in some cases, detecting problems that have not been noticed before.

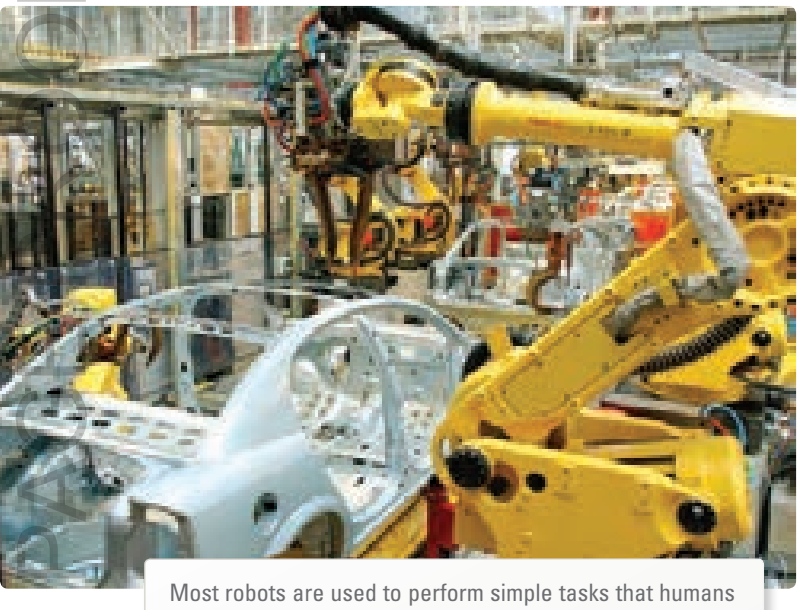
Many of the earliest cars were fuelled by steam.

ONLINE PROOFS

Untouched by human hands

Robots are compound machines that perform physical tasks without direct human assistance. They can be used to do jobs that are unpleasant, dangerous or boring. Robots can work in hot weather, cold weather, under water, under the ground, in outer space and in noisy places. They don't spread germs and they don't get tired.

Most robots are controlled by computers. Some are guided by remote-control units — similar to those used to operate DVD players and TV sets. Some robots can 'see' and 'hear' using video cameras and microphones.



Most robots are used to perform simple tasks that humans would find unpleasant, boring or dangerous. These robots are used to put the parts of a car body together.

Robot vacuum cleaners

No time to clean the house? Maybe a robotic vacuum cleaner can do the work for you. These robotic vacuums are really compound machines that contain a variety of sensors, motors and computer circuits. They are able to sense how large a room is, whether there is something blocking their path and how long it will take to get the vacuuming done. They even find their way back to a charging station when they are low on battery capacity.

Most robot vacuums have five motors in total and are driven by two wheels controlled by two motors. The robot can turn depending on how fast each wheel turns. A third wheel can freely rotate and balances the robot. The other three motors control the vacuum suction, the side sweeping brush and an agitating brush.

What happens when the robot is brought into a new space to clean? It uses an infra-red beam to measure the approximate distance across a room. The computer then calculates approximately how long it should take for the robot vacuum to clean that room. It starts vacuuming at the centre of the room and spirals out until it reaches the perimeter or an obstacle. When either of these things happens, the robot avoids bumping into the walls or obstacle using a short-range infra-red sensor. Another infra-red sensor is directed at the area in front of the robot. Usually the return signal occurs very quickly from the ground, which is not very far away. However, if stairs or a 'void' are encountered, the return signal takes longer (this is called the 'cliff' effect); this is detected by the robot and it turns around or backs up to avoid disaster.

WHAT DOES IT MEAN?

The word *robot* comes from the Czech word *robota*, meaning 'forced labour'.

ONLINE PAGE PROOFS

UNDERSTANDING AND INQUIRING

REMEMBER

1 What is the difference between a simple machine and a compound machine?

2 What are sprockets?

3 Which type of simple machine do bicycle pedals act as?

4 Which class of lever is a bicycle handbrake?

5 Where do the following compound machines get the energy from to move and make things happen?
(a) Bicycle
(b) Car
(c) Train

6 Why is it necessary to use more energy to operate a machine than you can get out of it?

7 How do robots differ from other machines?

THINK

8 Suggest two reasons why steam was replaced by petrol as a fuel for cars.

9 Where is the load that a bicycle handbrake pushes against?

10 Is a bicycle handbrake a speed multiplier or a force multiplier? Explain your answer.

11 Machines are used to replace various parts of the human body. Artificial arms, hands and legs are all machines. More recently, artificial hearts have been implanted. What are the arguments for and against the use of a machine to replace a failing human heart? What do you think?

12 List some reasons robots would be very useful for packaging food products.

13 Robots are clearly very useful devices. They do, however, have some disadvantages. Construct a table to list the advantages and disadvantages of robots.

14 Should robots be used to replace humans wherever possible in jobs that are unpleasant or boring? Write your opinion and reasons for it.

INVESTIGATE

15 Find out how hydraulic machines such as hydraulic lifts, cranes or brakes work.

16 Find out what qualifications are needed to become a:
(a) mechanical engineer
(b) motor mechanic.

17 Use the internet or other resources to investigate one of the Australian inventions listed above right. Each of them is a compound machine. Report on when and by whom it was invented, how it works and how it makes life easier. Identify at least three simple machines that make the invention work.
(a) Rotary clothes hoist
(b) Victa lawn mower
(c) Stump jump plough

18 Microbots are robots that are small enough to be injected into your veins. Use the internet to answer the following questions about microbots.
(a) Which harmful things in your bloodstream could microbots be used to destroy?
(b) How does the size of a microbot compare with the size of:
(i) a bacterium
(ii) a human red blood cell?

IMAGINE

19 It is the year 2050. Computer-controlled robots are used to perform most jobs that humans did in the past. Teachers have been replaced by robots that talk, answer questions, set homework, mark tests and even punish misbehaving students. Robots drive cars, serve in shops, babysit children and even read the news on television.
(a) Write a story about a day in the life of a student your own age in the year 2050.
(b) What do you think about this imaginary year 2050? Is it really better?

BRAINSTORM

20 Cars are compound machines that people rely on to get around. Think of the advantages of having one; but think also of all of the problems that cars cause — air pollution is just one of them.
(a) Construct a table like the one below. In a small group, 'brainstorm' the advantages and disadvantages of cars, completing the table as you go.
(b) After you have completed your table, discuss the questions with your group.
(i) Are cars our essential servants? Could we live without them?
(ii) Do cars control our lives so much that they are our masters? Are we slaves to our cars?
(c) Finally, write one or two paragraphs to state your own opinion on whether the car is our servant or our master. Include reasons for your opinion.

The car — servant or master?

Advantages of cars	Disadvantages of cars

21 In a small team, brainstorm a list of the simple machines that you might find inside a typical family car.

22 List as many situations as you can in which robots could be used to rescue people where humans could not.

ONLINE PAGE PROOFS

STUDY CHECKLIST

SIMPLE MACHINES

- ☐ explain how a mechanical advantage can be obtained from simple machines such as levers, inclined planes, pulley systems and gears
- ☐ distinguish between speed- (or distance-) multiplying machines and force-multiplying machines
- ☐ describe the effects of forces that can cause objects to change the motion of an object
- ☐ recall that you cannot get any more energy out of a machine than you put in
- ☐ describe the action of levers in the human body

COMPOUND MACHINES

- ☐ distinguish between compound machines and simple machines
- ☐ identify how simple machines work together in compound machines such as bicycles, lifts, cranes and hydraulic brakes
- ☐ explain how friction can be reduced in machines to reduce energy losses

SCIENCE AS A HUMAN ENDEAVOUR

- ☐ explain how inclined planes made tasks easier in an ancient civilisation
- ☐ identify that mechanics and mechanical engineers need to know how simple and compound machines work to apply forces
- ☐ explain how sports scientists can use their knowledge of levers in the human body to improve the performance of athletes
- ☐ consider and discuss the advantages and disadvantages of a dependence on cars for transport
- ☐ identify some of the benefits of robots to humans

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ANSWERS for this chapter can be found online in your eBookPLUS.

Online section

This section of the chapter can be found online in your eBookPLUS.

9.6 Thinking tools: Single bubble maps and Venn diagrams eBookplus ONLINE ONLY

Individual Pathways

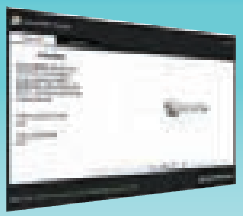
Activity 9.1	Activity 9.2	Activity 9.3
Investigating mechanical systems	Analysing mechanical systems	Investigating mechanical systems further
doc-6060	doc-6061	doc-6062

FOCUS activity

Access more details about focus activities for this chapter in your eBookPLUS. doc-XXXX

Interactivities

Spanner
Learn how a spanner multiplies force.



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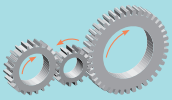
Gears
Learn how gears are used to make a wheel turn faster.



Searchlight ID: int-0025

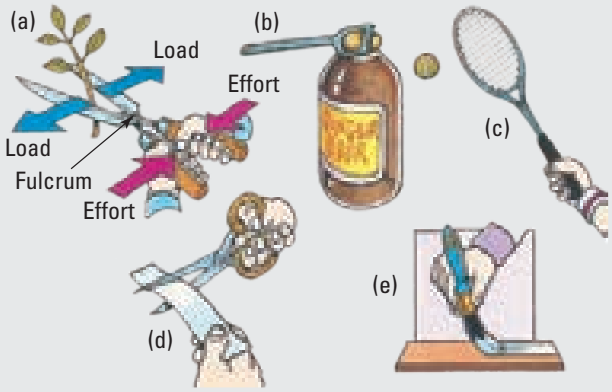
Gear ratios
An investigation looking at the effect of different-sized gears.

Searchlight ID: int-0746

LOOKING BACK

Link to assessON for questions to test your readiness **FOR** learning, your progress **AS** you learn and your levels **OF** achievement. www.assesson.com.au

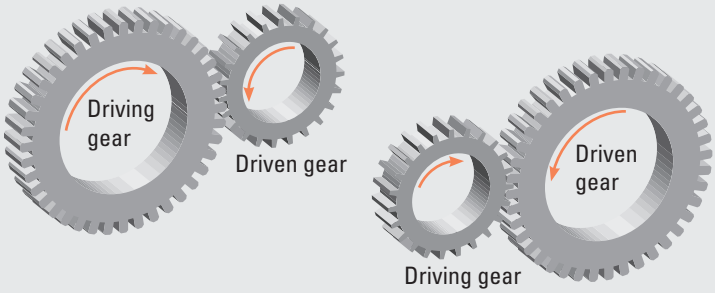
1 Copy the following diagrams and label the fulcrum, load and effort on each of the levers. The first diagram is labelled for you.



2 A student uses a pencil and ruler to model a first-class lever. It is tested by lifting 20-cent coins placed at one end of the ruler.
- (a) Draw a diagram to show how a pencil and ruler can be set up to model a first-class lever. Label the fulcrum, effort and load.
- (b) Calculate the mechanical advantage of the lever when it uses four coins to lift 12 coins.
- (c) If the 12 coins are placed six centimetres from the fulcrum, how far should the four coins be from the fulcrum to lift the larger pile of coins?

3 A flight of stairs is an example of a simple machine.
- (a) Which simple machine is a flight of stairs most similar to?
- (b) Are stairs force multipliers or speed multipliers? Explain your answer.

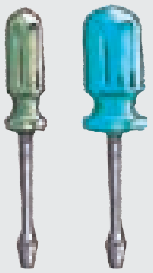
4 Which of the following is a speed multiplier and which is a force multiplier?



5 The plank below is 3.6 metres long. It is being used as a lever to lift a 40-kilogram box. This represents a load of 400 newtons.

- (a) If the fulcrum were placed in the centre of the plank, what downward effort would the man on the right of the diagram need to apply to raise the box?
- (b) If the man wants to push down on the end of the plank with an effort of only 200 newtons:
  - (i) how far along the plank should the fulcrum be
  - (ii) what would the mechanical advantage of the lever be?
- (c) How could the mechanical advantage of the lever be increased?
- (d) Is the plank being used as a speed multiplier or a force multiplier? Explain your answer.
- (e) Suggest a different way of using the plank as a simple machine to get the box into the truck.

6 Imagine that you wanted to drive a screw into a length of wood. If you had a choice of using one of the screwdrivers illustrated on the right, which one would you use? State a reason for your choice.



7 A softball bat is an example of a speed-multiplying lever.
- (a) Explain why the softball bat is not a force-multiplying lever.
- (b) Where is the fulcrum of the softball bat?
- (c) Which class (first, second or third) of lever is the softball bat?
- (d) Which other lever is used to help the softball on its way at high speed?

8 The bicycle shown below is made up of many simple machines. Identify as many as you can. Classify the simple machines that you identify as levers, inclined planes, wheels and axles, pulleys and gears. If you look thoroughly, you might be surprised at how many you find.

9 Create a poster or a series of PowerPoint slides to explain how one of the following machines works. Ensure that you indicate whether the machine is a speed multiplier or a force multiplier.
- (a) Water tap
- (b) Eggbeater
- (c) Corkscrew
- (d) Bicycle gears

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- 9.4 Thinking tools: Single bubble maps and Venn diagrams
- 9.5 Summing up
- 9.6 Looking back crossword

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Paper, Scissors, Robot

SEARCHLIGHT ID: PRO-0089

Scenario

Robots are highly advanced electrical machines that can be programmed to perform specific tasks. Like all compound machines, they are made up of many smaller interacting devices that are referred to by engineers as simple machines. In general, there are considered to be seven types of simple machine — lever, screw, inclined plane, gear, pulley, wheel and axle, and wedge.

Our bodies are able to move around because the muscles, bones, tendons and ligaments also act like simple machines. For example, an incisor is really an organic form of a wedge, while the movement of your forearm is possible because it is a lever, with your elbow acting as the fulcrum.

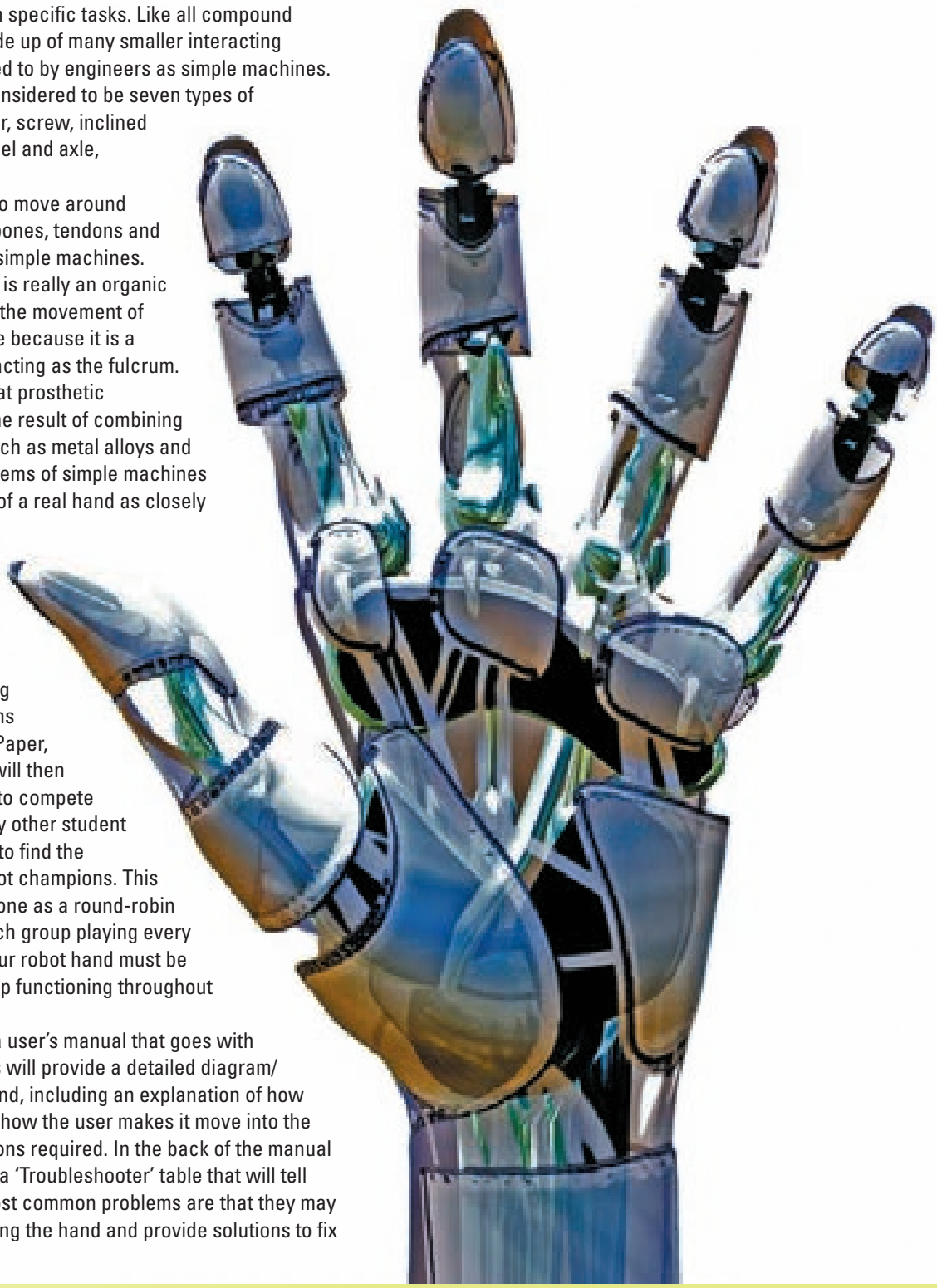
The robotic hands that prosthetic engineers design are the result of combining processed materials such as metal alloys and polymers to create systems of simple machines that imitate the motion of a real hand as closely as possible.

Your task

- You are going to design and build a robot hand that is capable of performing all of the hand motions used in the game of Paper, Scissors, Rock. You will then use your robot hand to compete with those created by other student groups in your class to find the Paper, Scissors, Robot champions. This tournament will be done as a round-robin competition, with each group playing every other group once. Your robot hand must be sturdy enough to keep functioning throughout the tournament.
- You will also create a user's manual that goes with your robot hand. This will provide a detailed diagram/plan of your robot hand, including an explanation of how it is constructed and how the user makes it move into the three different positions required. In the back of the manual there should also be a 'Troubleshooter' table that will tell the user what the most common problems are that they may experience when using the hand and provide solutions to fix those problems.

Process

Open the ProjectsPLUS application for this chapter located in your eBookPLUS. Watch the introductory video lesson and then click the 'Start Project' button to set up your project group. You can complete this project individually or invite other members of your class to form a group. Save your settings and the project will be launched.



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